VERIFYING NUTRIENTS AS A STRESSOR AND REVISING PHOSPHORUS ENDPOINTS FOR WISSAHICKON CREEK, PA

MJ Paul
Tetra Tech

TWO PART TALK

- Part 1 – Verifying phosphorus as a cause of stress to aquatic life in the Wissahickon Creek, PA
- Part 2 – Revision of the TP endpoint for the PA Piedmont ecoregion

PART 1: STRESSOR VERIFICATION

GOAL

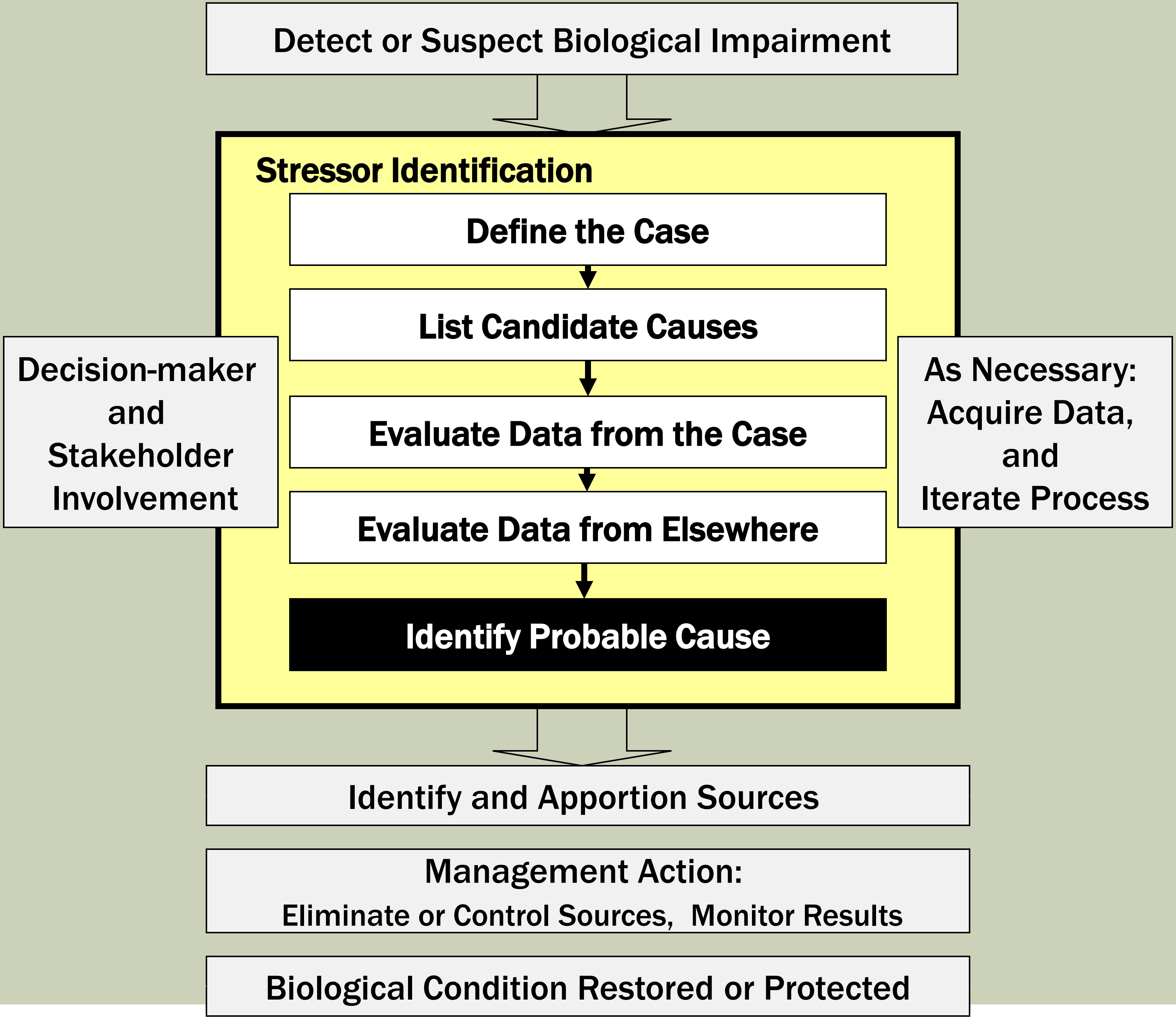
- Verify nutrients as a contributing cause of aquatic life use (ALU) impairment in the Wissahickon
  - Nutrients listed as cause of impairment in 1996 and relisted in subsequent IR cycles
  - Some have argued that nutrients not “the” cause of ALU impairment
  - EPA would like to verify that nutrients are, indeed, <u>a</u> cause of ALU impairment in this stream.

IDENTIFICATION VS. VERIFICATION

- Stressor Identification (SI) is a standardized method of evaluating candidate causes of ALU impairment and identifying those that are likely (EPA CADDIS)
  - Long process, comprehensive.
  - http://www.epa.gov/caddis/si_home.html

- “Stressor verification” – alternative; using the framework of the SI process to “verify” that nutrients are defensible cause of stress based on existing evidence

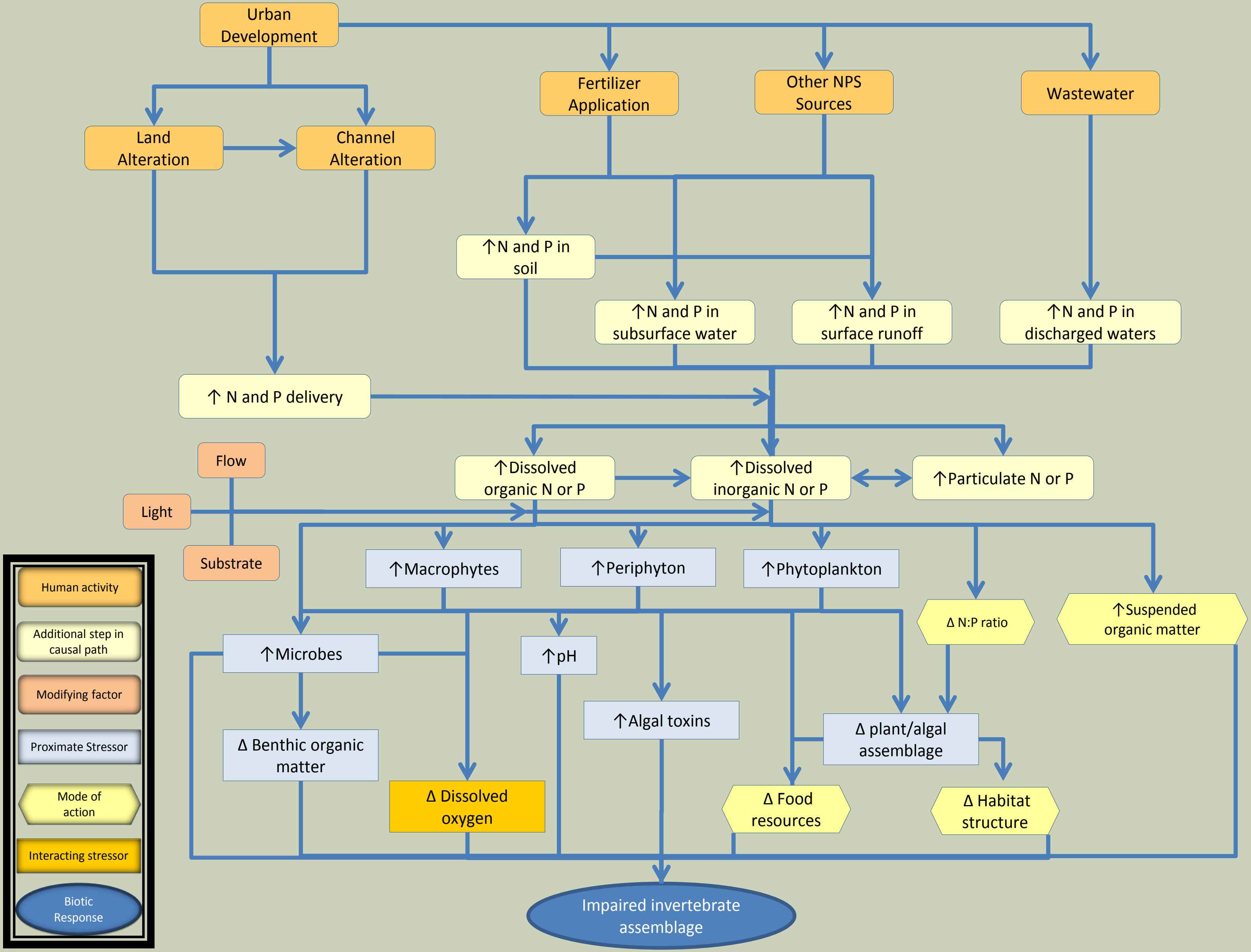
- Hypothesis driven: if nutrients are a cause, we expect to see the following…and then test these hypotheses.


Detect or Suspect Biological Impairment
Stressor Identification
Define the Case
List Candidate Causes
Evaluate Data from the Case
Evaluate Data from Elsewhere
Identify Probable Cause
Decision-maker and Stakeholder Involvement
As Necessary: Acquire Data, and Iterate Process
Identify and Apportion Sources
Management Action:
Eliminate or Control Sources, Monitor Results
Biological Condition Restored or Protected

STRESSOR IDENTIFICATION

SI Process	Us
Conceptual Model	Conceptual Model
List Candidate Causes	Nutrient Cause
Data Synthesis	Data Synthesis
Consider Evidence from the Case	Consider Evidence from the Case
Consider Evidence from outside the Case	Consider Evidence from outside the Case
Identify likely causes	Verify Nutrients

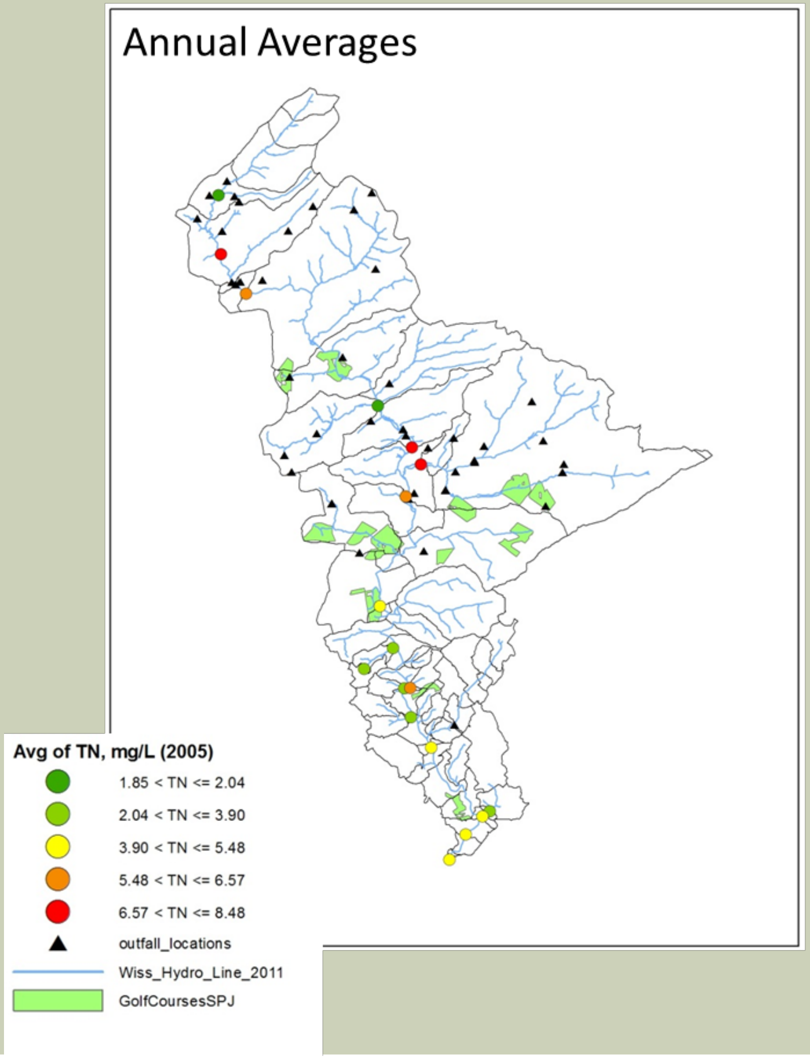
Wissahickon Conceptual Model

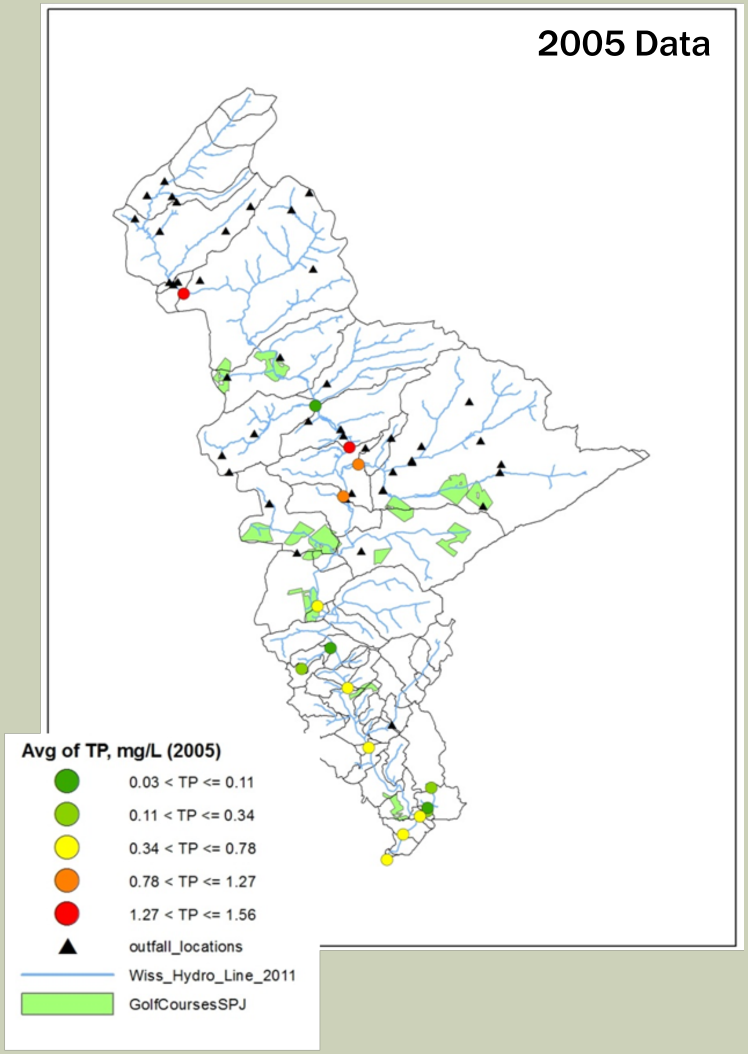


MODEL "HYPOTHESIS" LEADS TO FOLLOWING PREDICTIONS

1. Evidence of increased nutrient concentrations in the stream associated with runoff and discharges, as well as baseflow;
2. Evidence of altered N:P ratio associated with elevated nutrient loads;
3. Evidence of increased algal/plant biomass at locations pursuant or coincident with elevated nutrients;
4. Evidence of altered plant/algal assemblage structure pursuant or coincident with elevated nutrients;
5. Evidence of altered suspended organic matter composition pursuant or coincident with elevated nutrients;
6. Evidence of altered dissolved oxygen dynamics (greater diel flux, lower minima, and higher maxima) pursuant or coincident with elevated alga/plant biomass;
7. Evidence of altered pH pursuant or coincident with elevated alga/plant biomass;
8. Evidence of altered invertebrate assemblage composition pursuant or coincident with elevated alga/plant biomass, altered dissolved oxygen, altered pH, altered assemblage composition.

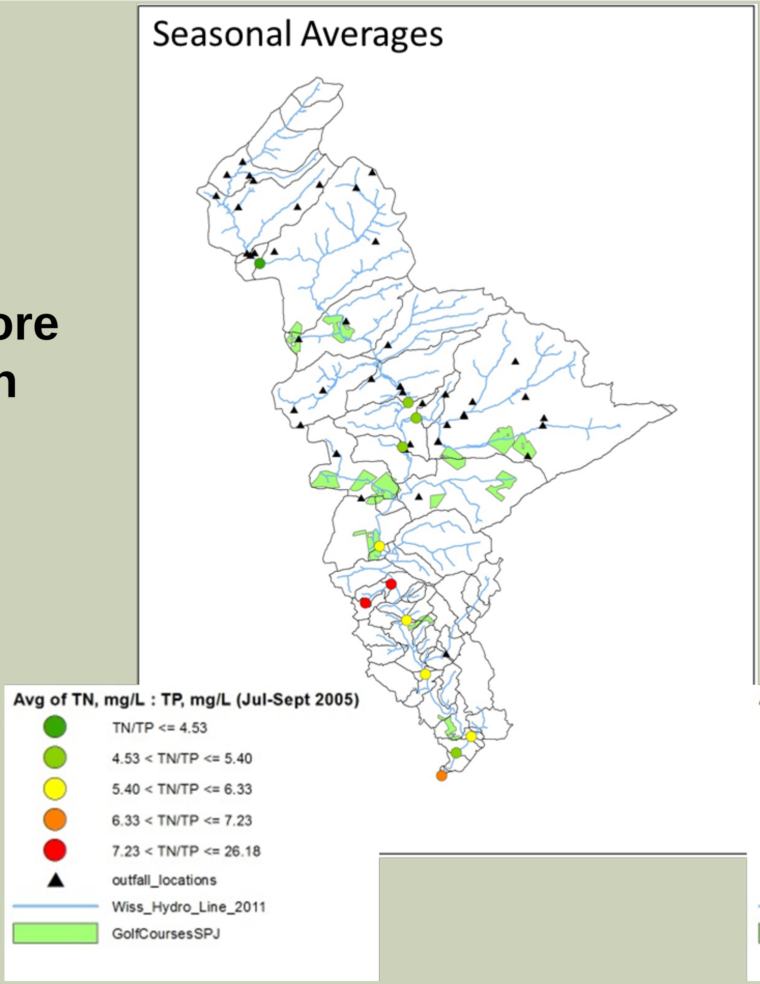
PREDICTION 1 – INCREASED CONCENTRATIONS

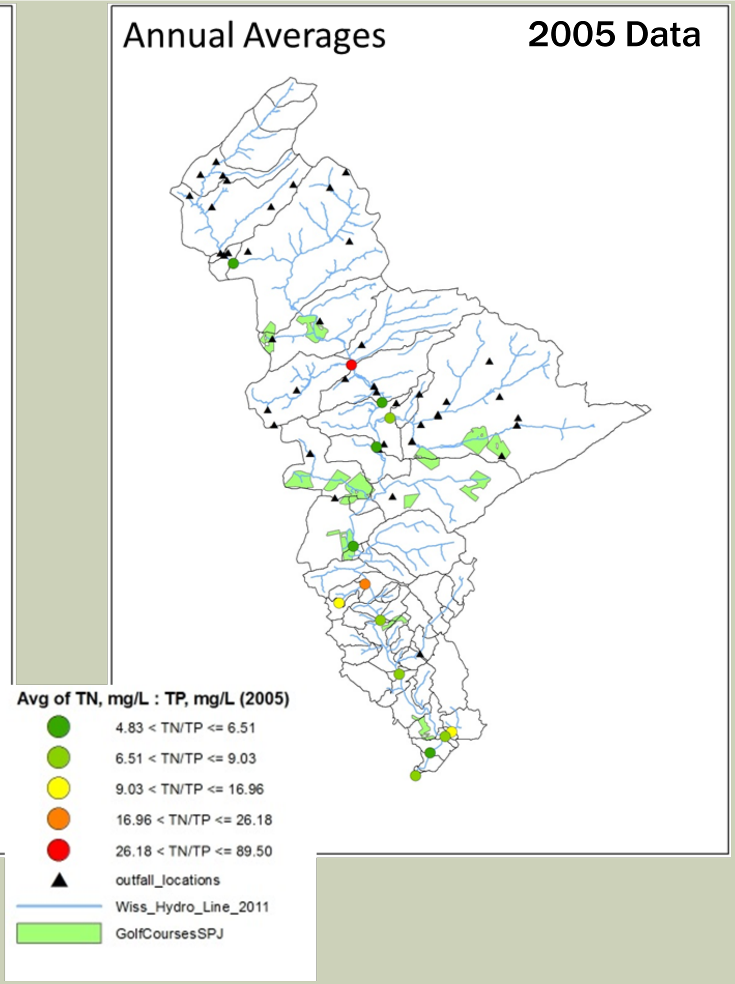




PREDICTION 2 – ALTERED RATIOS

N:P > 7 suggests more P limitation

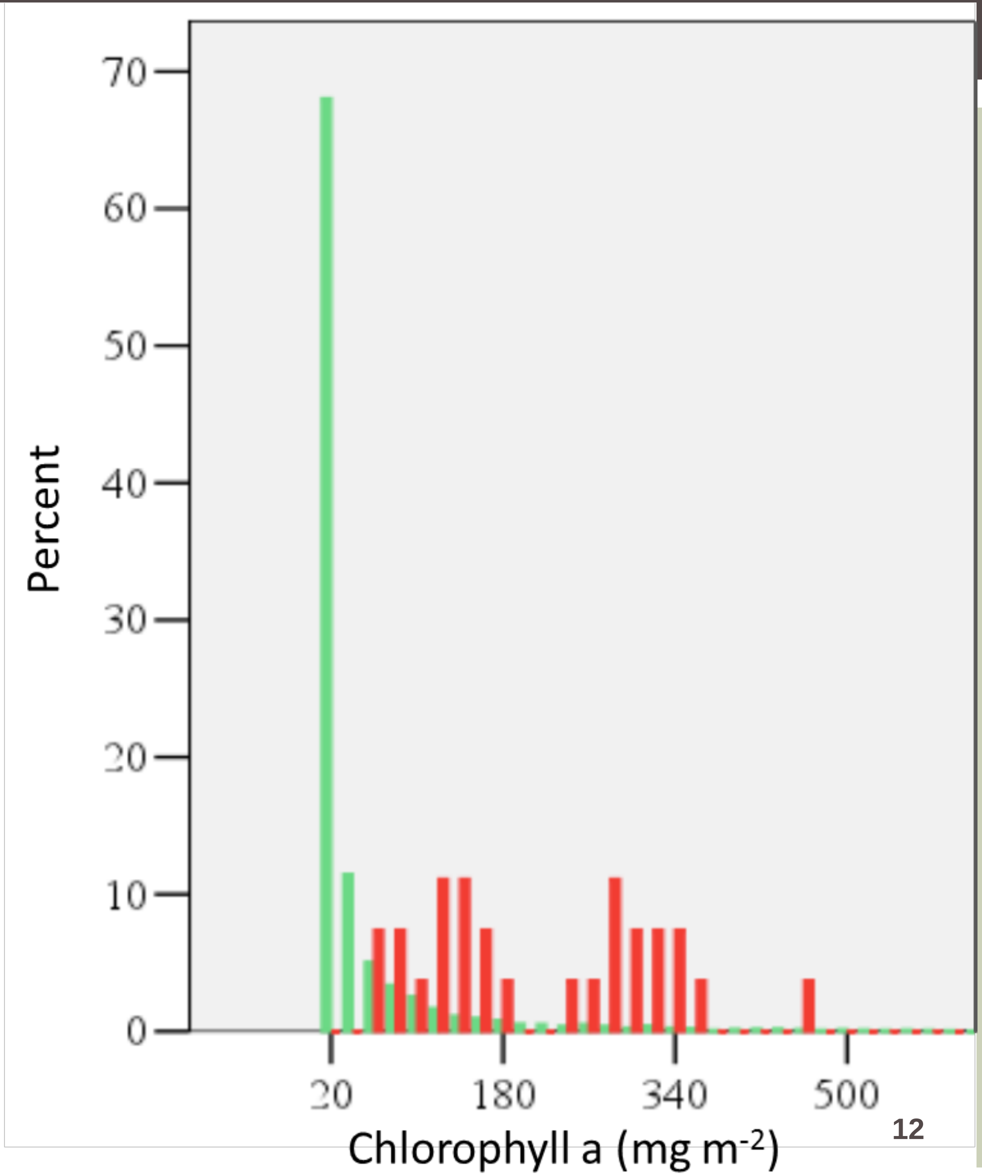




Stronger N in growing season – P enrichment relative to region (83:1)

PREDICTION 3 – INCREASED CHL A

- Clear evidence that chl a reaches instantaneous values considered well above nuisance levels, or levels consistent with harm to aquatic life.
- Chl a vs. nutrient relationships vary in space and time due to factors such as shade, substrate, and scour.



PREDICTION 4 – ALTERED ALGAL ASSEMBLAGE

Dr. Lei Zheng reviewed taxa lists and diatom reports, confirms conclusions that taxa are all diagnostic of high nutrient concentrations.

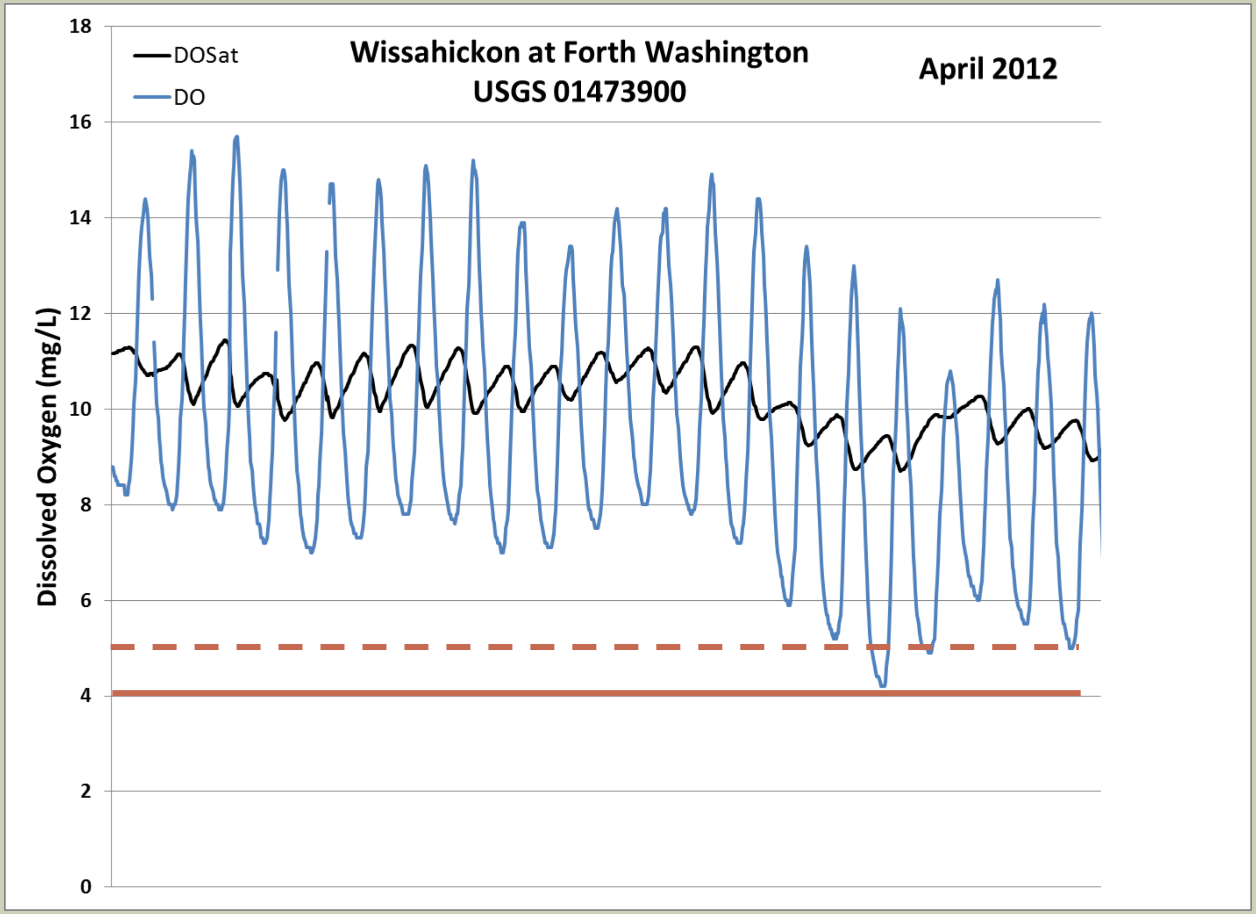
"Nitzschia inconspicua, Nitzschia amphibian, Navicula minima, Rhoicosphenia curvata, Melosira varians, Amphora pediculus, Synedra fasicualuata, Navicula gregaria, Navicula viriduna var. *rostellata, Gomphonema parvulum, Cocconeis placentuala* **<u>are all strong nutrient indicators</u>**."

PREDICTION 5 – ALTERED SUSPENDED ORGANIC MATTER COMPOSITION

- Diatom nutrient content data (Carrick and Godwin 2006) indicate that cells are enriched with N and P relative to "balanced growth" needs.
  - Average C:N:P ratio in Wissahickon = 8:1:1 (based on average concentrations
  - Much lower than the Redfield ratio (106:16:1) that reflects balanced growth for algae
- Algae are high nutrient taxa and storing excess nutrients- both indicate enrichment.

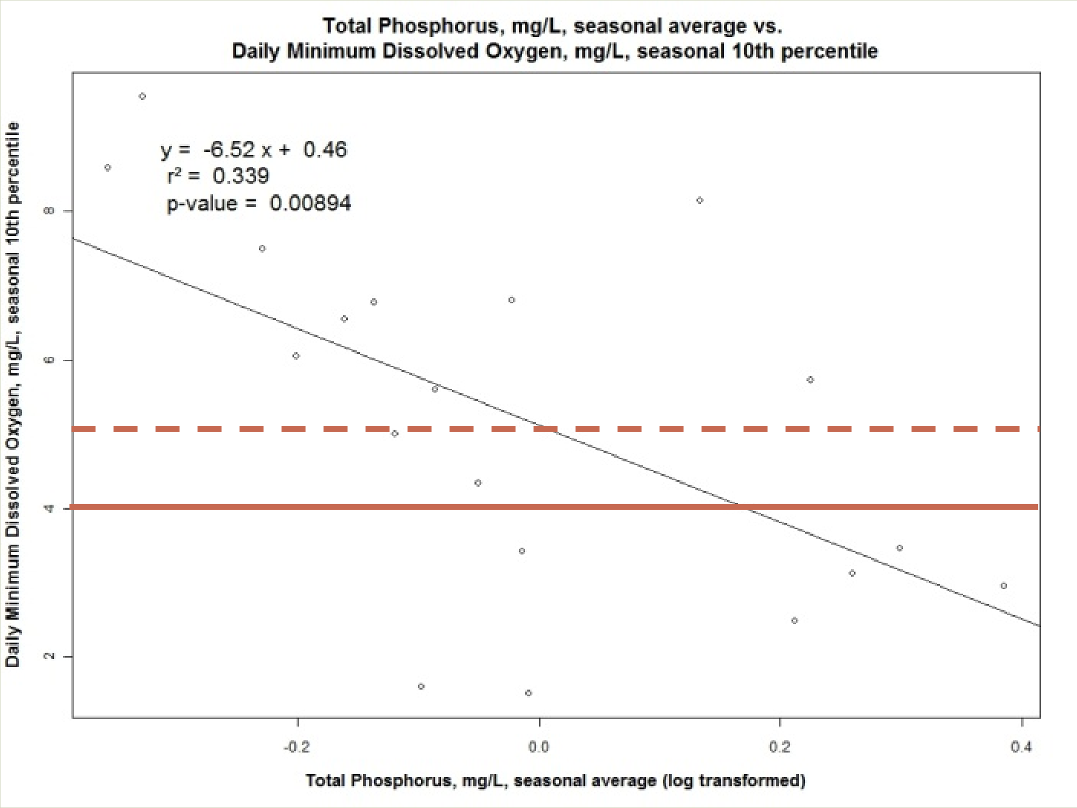
PREDICTION 6 – ALTERED OXYGEN DYNAMICS

- Large DO swings are typical in the Wissahickon



PREDICTION 6 – ALTERED OXYGEN DYNAMICS

- Violations of DO standards



- PADEP (2002) study found the same thing – reduced minima and increased diel flux

PREDICTION 7 – ALTERED PH

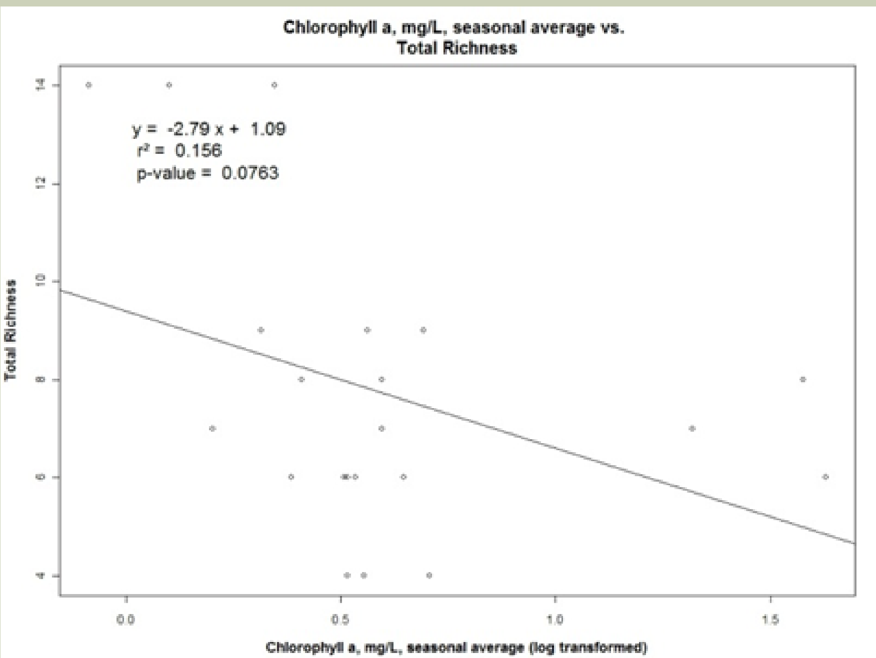
- Supports brown pathway effects – increased respiration fueled by nutrients
- Increased CO_2 – makes carbonic acid (H_2CO_3) – lowers pH

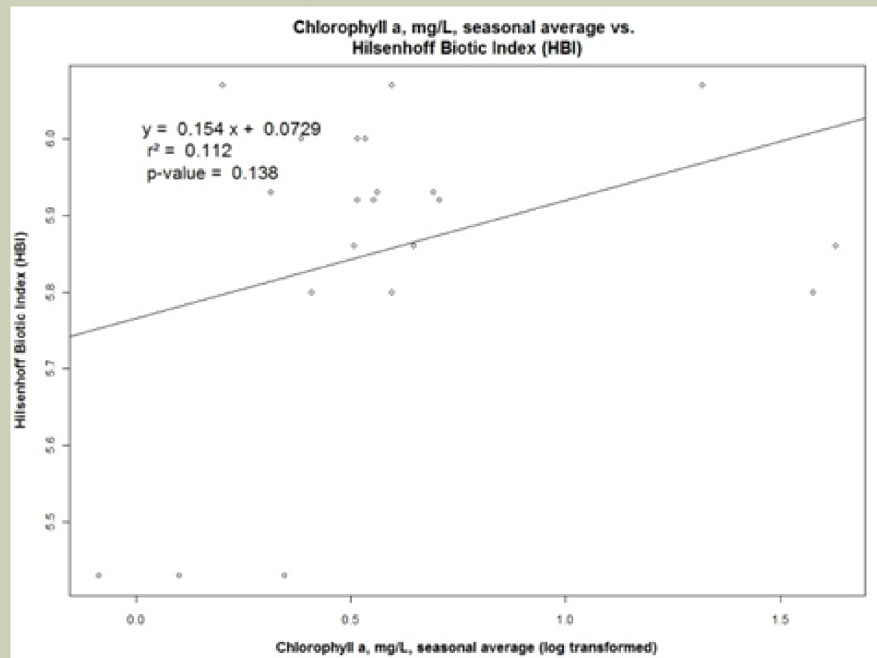
Annual Averages	Daily Avg pH	Daily Max pH	Daily Min pH	Daily pH Range
↑TP	↓	↓	↓	NS
Seasonal Averages				
↑TKN	↓	↓	NS	↓
↑TP	↓	↓	↓	NS

2005 Data

PREDICTION 8 – ALTERED INVERTEBRATES

- Richness declines and tolerance increases with chlorophyll
- P values above 0.05, but below 0.15
- Responses are non-linear

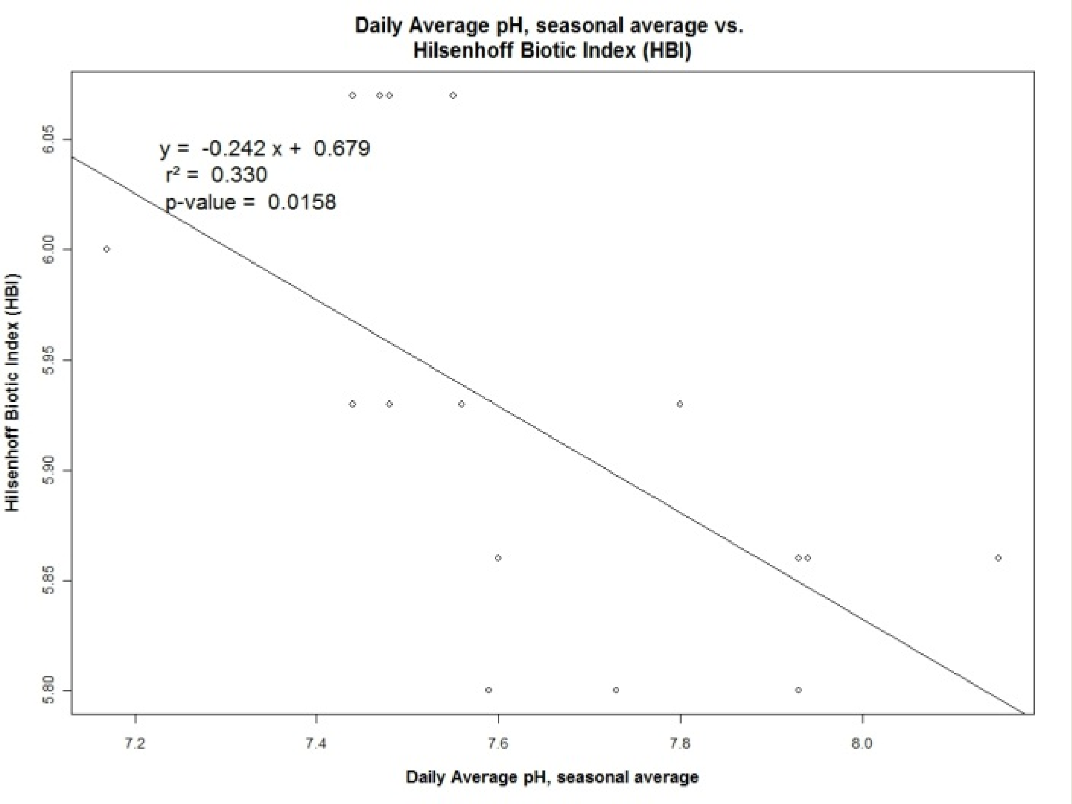




2005 Data

PREDICTION 8 – ALTERED INVERTEBRATES

- Tolerance increases with lower pH too.



2005 Data

SUMMARY

	Prediction	Evidence Supporting
1	Increased nutrient concentrations in the stream associated with runoff and discharges, as well as baseflow	Yes
2	Evidence of altered N:P ratio associated with elevated nutrient loads	Yes
3	Evidence of increased algal/plant biomass at locations pursuant or coincident with elevated nutrients	Yes
4	Evidence of altered plant/algal assemblage structure pursuant or coincident with elevated nutrients	Yes
5	Evidence of altered suspended organic matter composition pursuant or coincident with elevated nutrients	Limited
6	Evidence of altered dissolved oxygen dynamics (greater diel flux, lower minima, and higher maxima) pursuant or coincident with elevated alga/plant biomass	Yes
7	Evidence of altered pH pursuant or coincident with elevated alga/plant biomass	Yes
8	Evidence of altered invertebrate assemblage composition pursuant or coincident with elevated alga/plant biomass, altered dissolved oxygen, altered pH, altered assemblage composition	Limited

SUMMARY – MULTIPLE LINES

Type of Evidence	Description	Wissahickon
Consistency of Evidence	Confidence in the argument for or against a candidate cause is increased when many types of evidence consistently support or weaken it.	+++ (All evidentiary lines convincingly support the case for the cause)
Explanation of Evidence	Confidence in the argument for a candidate cause is increased when a post hoc mechanistic, conceptual, or mathematical model reasonably explains any inconsistent evidence.	++ (The only inconsistent evidence is from invertebrate response which can be defensibly explained based on the uniformity of impact and the confounding effect of co-occurring stressors with nutrients)

PART 2:
REVISING THE PIEDMONT TP ENDPOINTS

Stressor-
Response
Guidance
and
SAB Review

APPROACHES FOR DEVELOPING NUTRIENT TARGETS

- Population derived approaches*
- Modeled reference expectation*
- Nutrient-response based approaches*
- Mechanistic Models
- Other Studies*
- Weight-of-evidence
  - Consider all of the above
  - Weight evidence

*Used in First Endpoints Derivation Effort

SUMMARY OF FIRST ENDPOINTS ANALYSIS (TOTAL PHOSPHORUS)

	Approach	TP Endpoint (µg/L)
Reference Approach		**2-37**
	Reference Site 75th Percentile	16-17
	All Sites 25th Percentile	17
	Modeled Reference Expectation	2-37
Stressor-Response		**36-64**
	Conditional Probability – EPT taxa	38
	Conditional Probability - % Clingers	39
	Conditional Probability - % Urban Intolerant	64
	Conditional Probability - Diatoms TSI	36
Other Literature		**13-100**
	USEPA Recommended Regional Criteria	37
	USEPA Regional Criteria Approach – Local Data	40-51
	Algal Growth Saturation	25-50
	Nationwide Meta-Study TP-Chlorophyll	21-60
	USGS Regional Reference Study	20
	USGS National Nutrient Criteria Study	13-20
	New England Nutrient Criteria Study	40
	Virginia Nutrient Criteria Study	50
	New Jersey TDI	25-50
	Delaware Criteria	50-100

First Endpoints 2007/08

EMPIRICAL APPROACHES FOR NUTRIENT CRITERIA DERIVATION

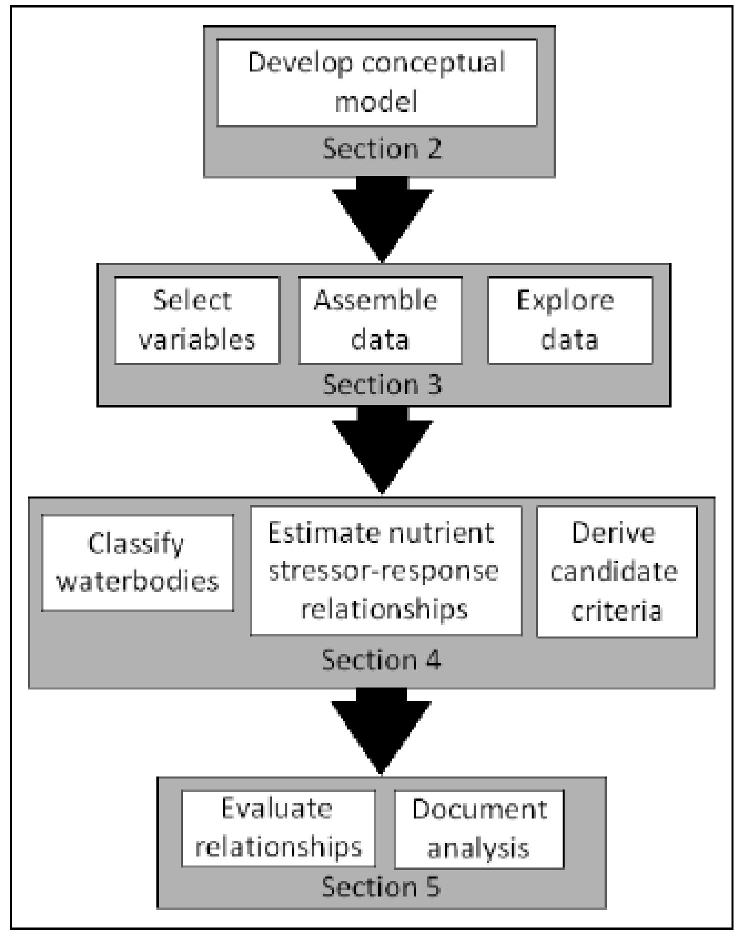
- EPA provides additional guidance on using stressor-response relationships to derive numeric nutrient criteria
- Particular focus on stressor-response analysis and recommendation for nutrient criteria development
- Draft: 2009
- SAB Review: 2009/2010
- Final: 2010

EPA United States Environmental Protection Agency | Office of Water | EPA-820-S-10-001
Mail code 4304T | November 2010

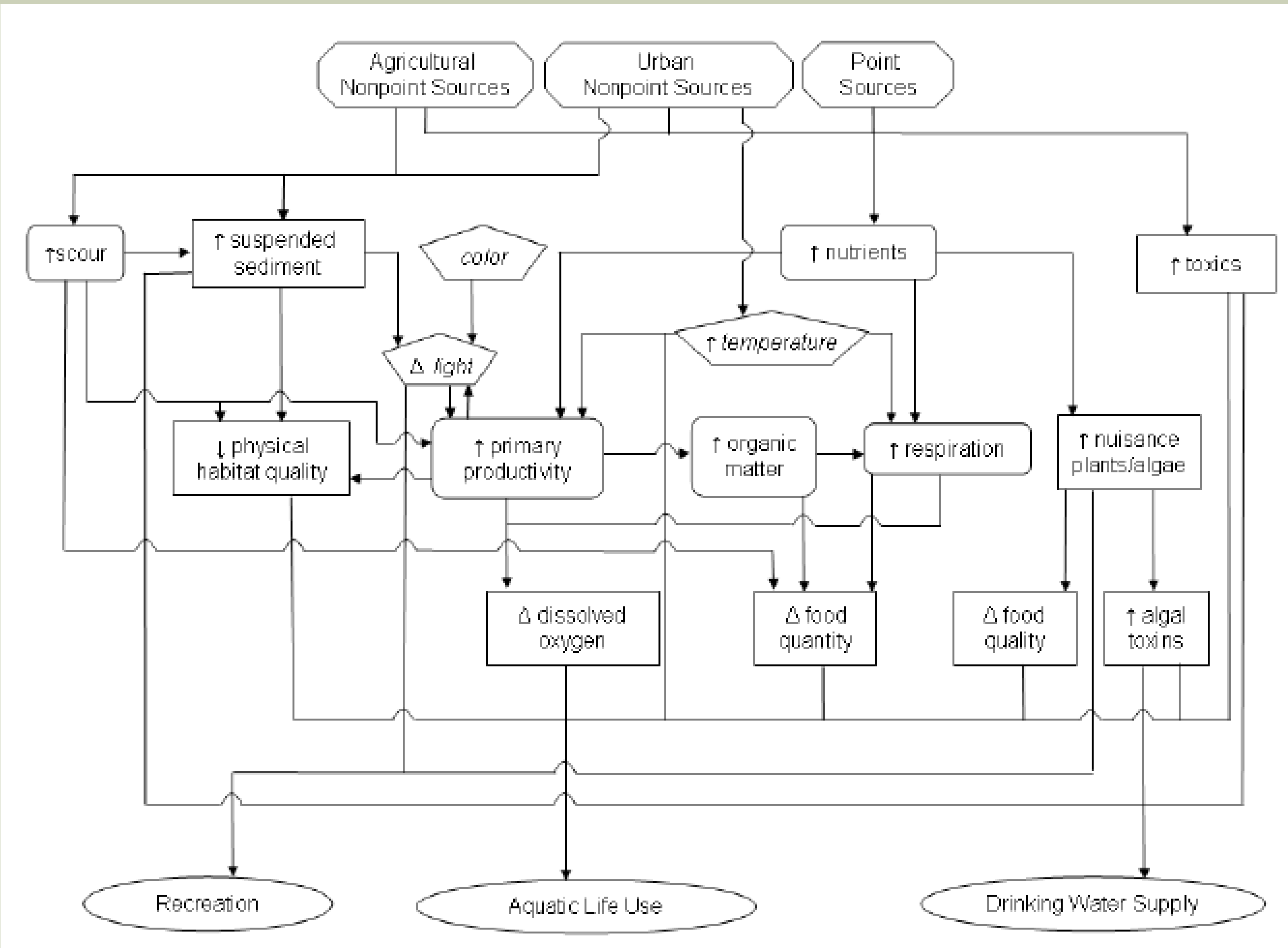
Using Stressor-response Relationships to Derive Numeric Nutrient Criteria

WHAT DOES NEW GUIDANCE RECOMMEND?

- Lays out 4 step process:
  - Conceptual Model
  - Data Assembly and Exploration
  - Estimate stressor-response relationship
  - Model review and evaluation



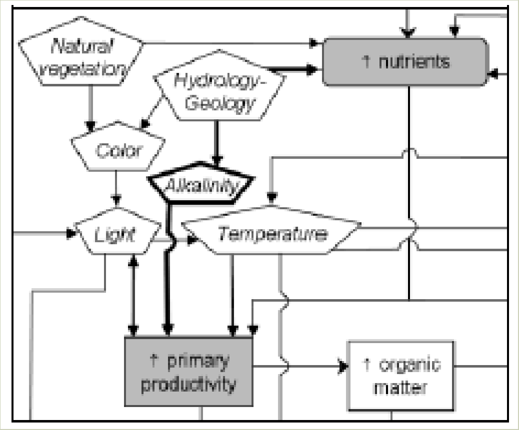
CONCEPTUAL MODELS



- Scientific basis for stressor-response model

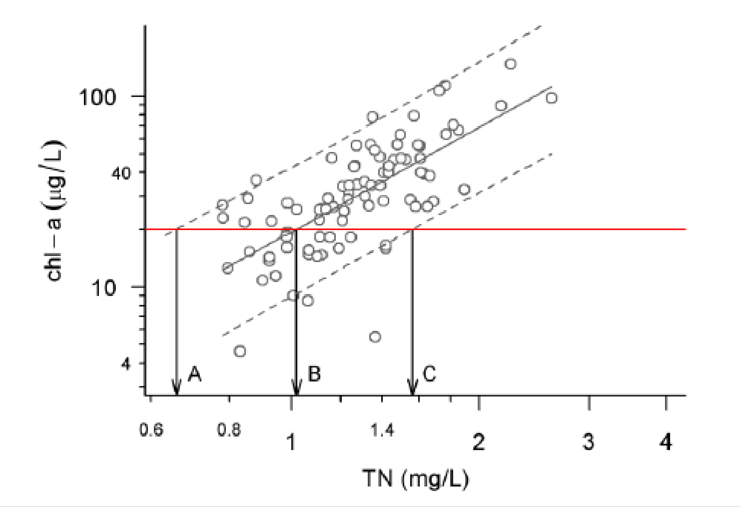
ASSEMBLE AND EXPLORE DATA

- Identifying co-variates/blocked pathways for consideration in modeling
- Conditional probability presented as an exploratory approach, rather than a criteria derivation approach – upper bounds and exploration of ranges



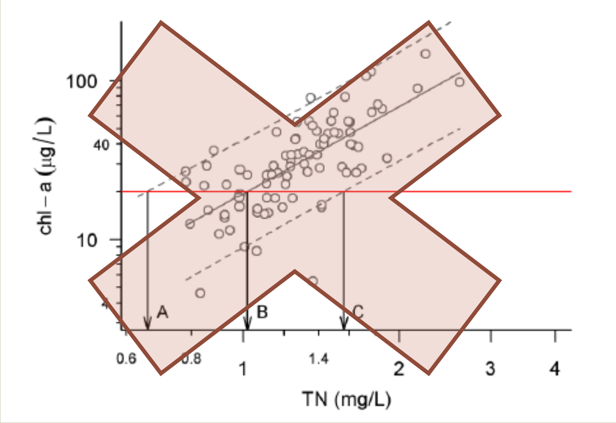
ANALYZE DATA

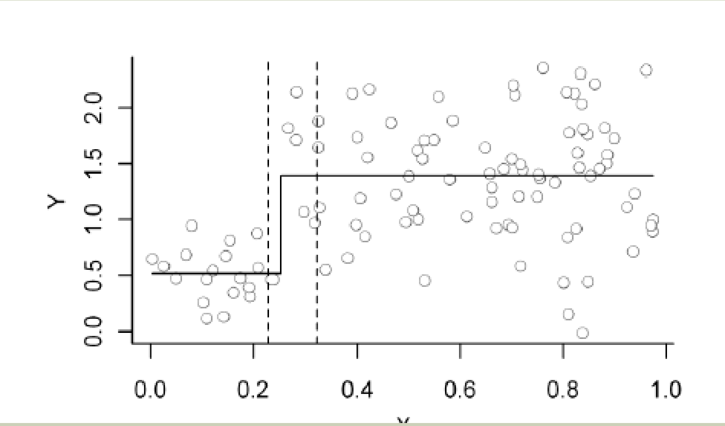
- Classify, stressor-response estimation, and criteria derivation
- Classification reduces variation from confounding variables (e.g. ecoregion, land cover, stream size)
- Focus on simple linear regression models with interpolation



ANALYZE DATA

- Extensions to multiple linear regression
  - Explore other factors/confounding variables and resulting relationship
- Quantile regression
- Changepoint Analysis
  - Underwent some criticism, so recommended only when ecologically and statistically relevant





EVALUATE AND DOCUMENT

- Model accuracy
  - How well does model account for confounding effects?
  - How accurate does it depict the unique nutrient effect?
  - How does it compare to other independent estimates?
- Model precision

- Report model statistics (e.g., prediction and confidence intervals, residual analysis, etc.)
- Communicate classification and evaluate effects
- Document

SAB REVIEW

- EPA Science Advisory Board reviewed draft 2009 document and comments incorporated into final 2010 document

- Major issues:
  - Using empirical stressor-response models was NOT a concern

  "The **stressor-response approach is a legitimate, scientifically based method for developing numeric nutrient criteria if the approach is appropriately applied (i.e., not used in isolation but as part of a weight-of-evidence approach)**. We encourage the Agency to continue this important work."

  - Clarify scope, intended use and context within other guidance
  - Does not prove cause-effect, therefore use as weight of evidence with other approaches
  - Communicate uncertainty
  - Does not address downstream impacts

SAB REVIEW

- Recommendations:
  - Discuss cause and effect more
  - Utility/limitations of statistical methods
  - Analysis and data needed to correctly identify predictive relationships
  - More guidance on when and how to use various methods/approaches
  - How to link designated uses and stressors
  - More specific and descriptive framework of steps in process
  - Train users

EPA RESPONSE

- Draft to Final
  - More on cause and effect in introduction
  - Causal model section added
  - Methods greatly reorganized and simplified, limitations discussed,
  - Expanded sections on data exploration/needs and analysis options
  - Expanded causal model section discusses linkages to designated uses
  - Refined framework

- EPA published response to comments

CONSEQUENCE

New Stressor-Response Guidance

+ Stressor-Response in Original Analysis

Desire to revise stressor-response line of evidence per new guidance

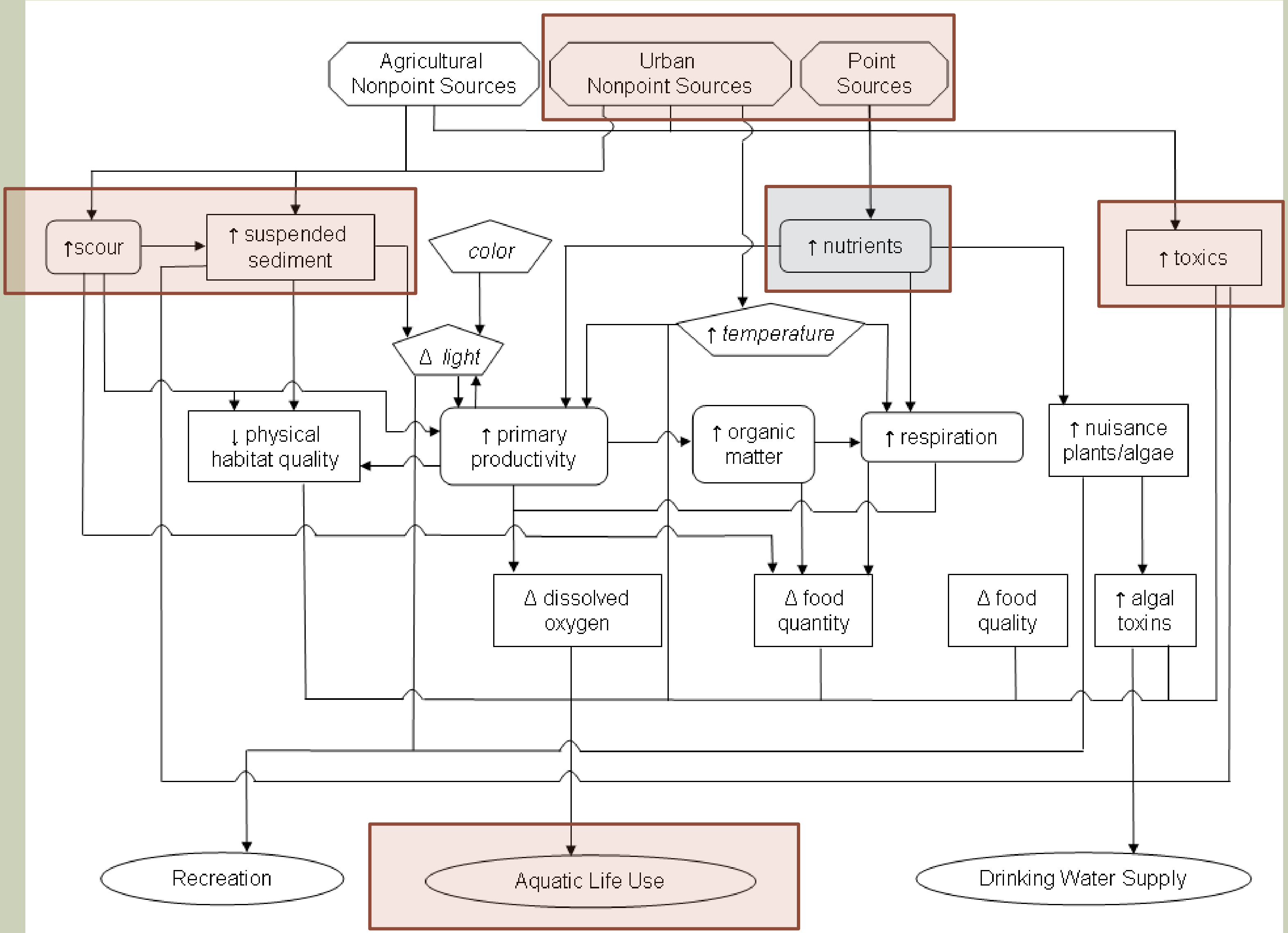
REVISED ENDPOINT

REVISIONS

- Update conceptual model;
- Compare/contrast response metrics with PA methods;
- Confounding stressors: Identify nutrient co-variates, explore and reduce co-variation as recommended in guidance (propensity scores, multiple regression, etc.);
- Use linear/non-linear simple regression with interpolation as recommended in guidance;
- Validate model outcomes with other data/sources;
- Report on accuracy/precision;
- Add mechanistic modeling line of evidence;
- Add additional scientific literature.

Updated Conceptual Model

Co-factors of Concern



Limited Data

Revisited Endpoint

COMPARING METRICS

MBSS Revised IBI - 2005

Piedmont
Number of Taxa*
Number of EPT *
Number of Ephemeroptera
% Intolerant Urban*
% Chironomidae
% Clingers

PADEP 2009 – Freestone IBI

Candidate Metric
Total Taxa Richness
Ephemeroptera + Plecoptera + Trichoptera Taxa Richness (PTV 0 – 4 only)
Beck's Index – version 3
Shannon Diversity
Hilsenhoff Biotic Index
% Sensitive Individuals (PTV 0 – 3 only)

CONFOUNDING CO-STRESSORS

- TP not correlated with many other stressors
- Propensity scores not needed – i.e. little appears to be confounding the nutrient effect per se.
- However, there are other stressors.

Spearman Rank Order Correlations

Variable	Nitrate	Total Nitrogen	Total Phosphorus	Dissolved Oxygen	pH	Conductivity	Sulfate	Turbidity	Instream	EPI Substrate	Embedded	Flow
Nitrate		0.988	0.061	0.248	-0.099	-0.081	-0.236	-0.027	0.015	0.061	-0.080	0.130
Total Nitrogen	0.988		0.099	0.239	-0.109	-0.070	-0.220	-0.011	0.002	0.043	-0.077	0.142
Total Phosphorus	0.061	0.099		-0.059	0.051	0.120	0.269	0.283	-0.145	-0.194	0.231	0.128
Dissolved Oxygen	0.248	0.239	-0.059		-0.029	-0.130	-0.181	-0.234	0.209	0.293	-0.193	0.232
pH	-0.099	-0.109	0.051	-0.029		0.548	0.518	-0.141	0.162	0.049	0.115	0.274
Conductivity	-0.081	-0.070	0.120	-0.130	0.548		0.730	-0.065	-0.205	-0.255	0.263	-0.112
Sulfate	-0.236	-0.220	0.269	-0.181	0.518	0.730		0.001	-0.182	-0.236	0.213	-0.034
Turbidity	-0.027	-0.011	0.283	-0.234	-0.141	-0.065	0.001		-0.101	-0.156	0.163	0.138
Instream	0.015	0.002	-0.145	0.209	0.162	-0.205	-0.182	-0.101		0.808	-0.423	0.512
EPI Substrate	0.061	0.043	-0.194	0.293	0.049	-0.255	-0.236	-0.156	0.808		-0.571	0.339
Embedded	-0.080	-0.077	0.231	-0.193	0.115	0.263	0.213	0.163	-0.423	-0.571		-0.109
Flow	0.130	0.142	0.128	0.232	0.274	-0.112	-0.034	0.138	0.512	0.339	-0.109	

Correlations in blue are more than or less than 0.5

Missing data is deleted pairwise

CONFOUNDING CO-STRESSORS

- Correlations with biology
- Bug metrics correlate with other stressors:
  - conductivity/SO4/habitat

Spearman Rank Order Correlations

Variable	Nitrate	Total Nitrogen	Total Phosphorus	Dissolved Oxygen	pH	Conductivity	Sulfate	Turbidity	Instream	EPI Substrate	Embedded	Flow
Intolerant Urban %	0.137	0.104	-0.268	0.235	-0.393	-0.612	-0.522	-0.164	0.247	0.371	-0.345	-0.086
Chironomid %	-0.082	-0.058	0.147	-0.232	0.284	0.483	0.373	0.200	-0.231	-0.332	0.300	0.007
Clinger %	0.093	0.057	-0.183	0.242	-0.212	-0.448	-0.351	-0.218	0.327	0.412	-0.353	0.075
Total Taxa	0.242	0.225	0.022	0.058	-0.280	-0.389	-0.411	0.025	0.111	0.138	-0.077	0.051
EPT Taxa	0.270	0.239	-0.159	0.263	-0.286	-0.553	-0.492	-0.171	0.289	0.383	-0.328	0.089
Ephemeroptera Taxa	0.286	0.263	-0.107	0.257	-0.231	-0.569	-0.434	-0.061	0.240	0.302	-0.238	0.112

Correlations in red are significant at $p < .05$

Missing data is deleted pairwise

CONFOUNDING CO-STRESSORS

- Percent Intolerant Urban Taxa
  - TP adds an additional 7% to r^2 (from 0.33 to 0.40)
- TP still matters

Regression Summary for the Dependent Variable of Intolerant Urban %

	b*	Standard Error of b*	b	Standard Error of b	t(330)	p-value
Intercept			27.139	1.912	14.195	0.00000
Conductivity	-0.499	0.049	-14.854	1.459	-10.182	0.00000
Total Phosphorus	-0.139	0.043	-4.251	1.308	-3.249	0.00128
Turbidity	-0.157	0.042	-4.637	1.255	-3.694	0.00026
Flow	-0.198	0.047	-10.666	2.500	-4.266	0.00003
EPI Substrate	0.221	0.047	6.604	1.404	4.702	0.00000
pH	-0.101	0.049	-3.026	1.477	-2.049	0.04123

R= .69996489 R^2= .48995084 Adjusted R^2= .48067722

F(6,330)=52.833 p<0.0000 Standard Error of estimate: 21.445

N=337

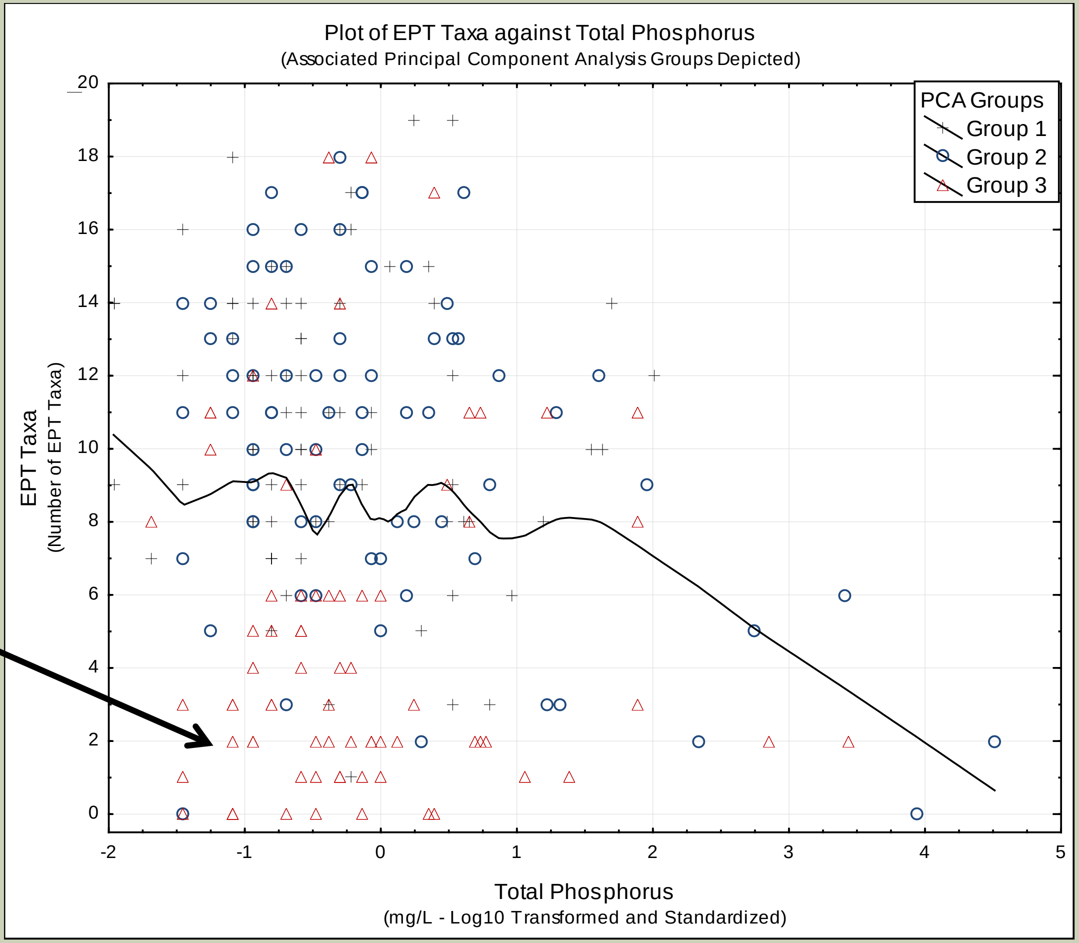
CONFOUNDING CO-STRESSORS

- Urbanization (and associated other stressors) a likely confounding effect in models;
- Goal: reduce effect of urbanization on stressor-response relationship;
  - Focus on nutrient effect on invertebrates without confounding effect
  - Remember: Goal to recommend a TP endpoint to protect Piedmont streams

CONFOUNDING CO-STRESSORS

Used PCA to identify 3 bins:
1 – least urban
3 – most urban

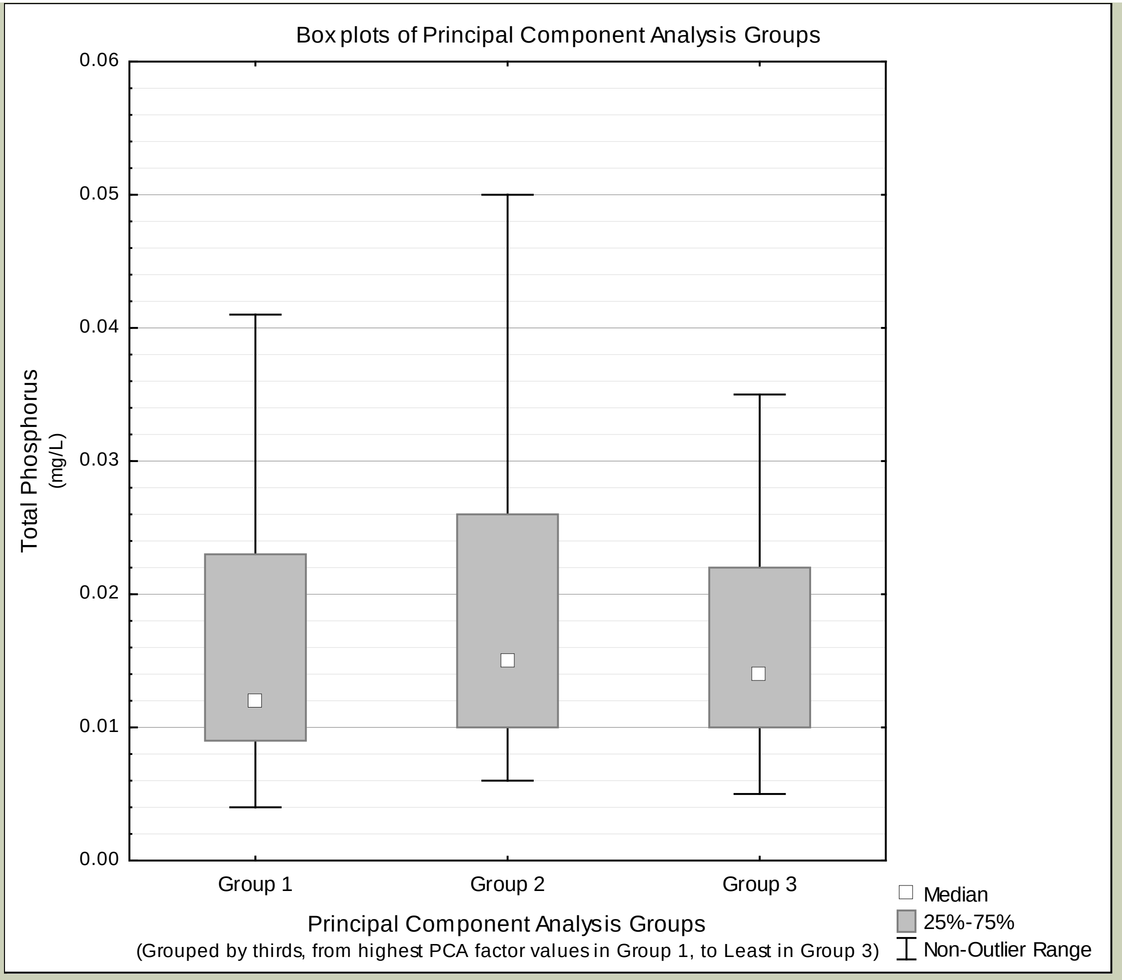
A lot of the "noise" on left end is urban effects



Revisited Endpoint

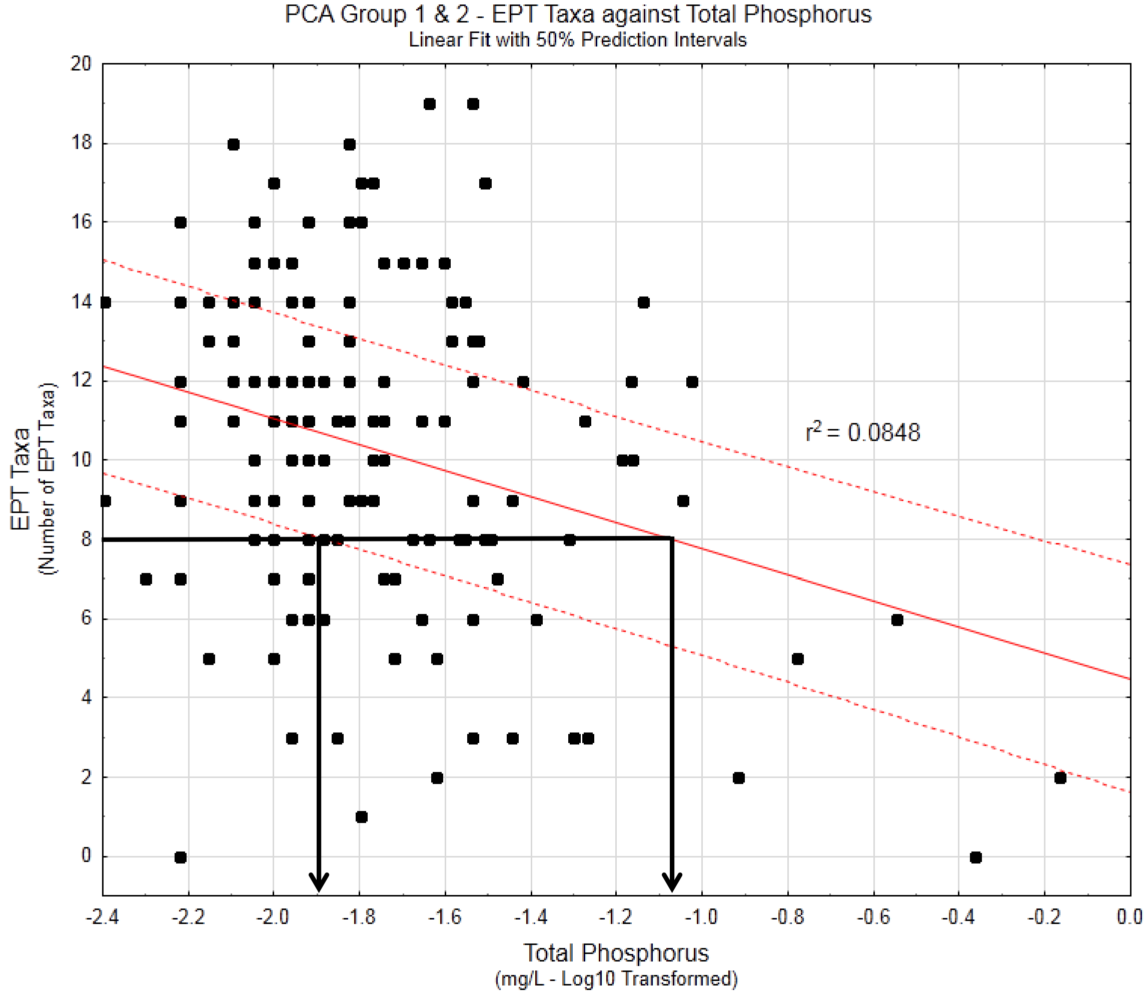
CONFOUNDING CO-STRESSORS

- TP pretty similar
- But urban stress very different



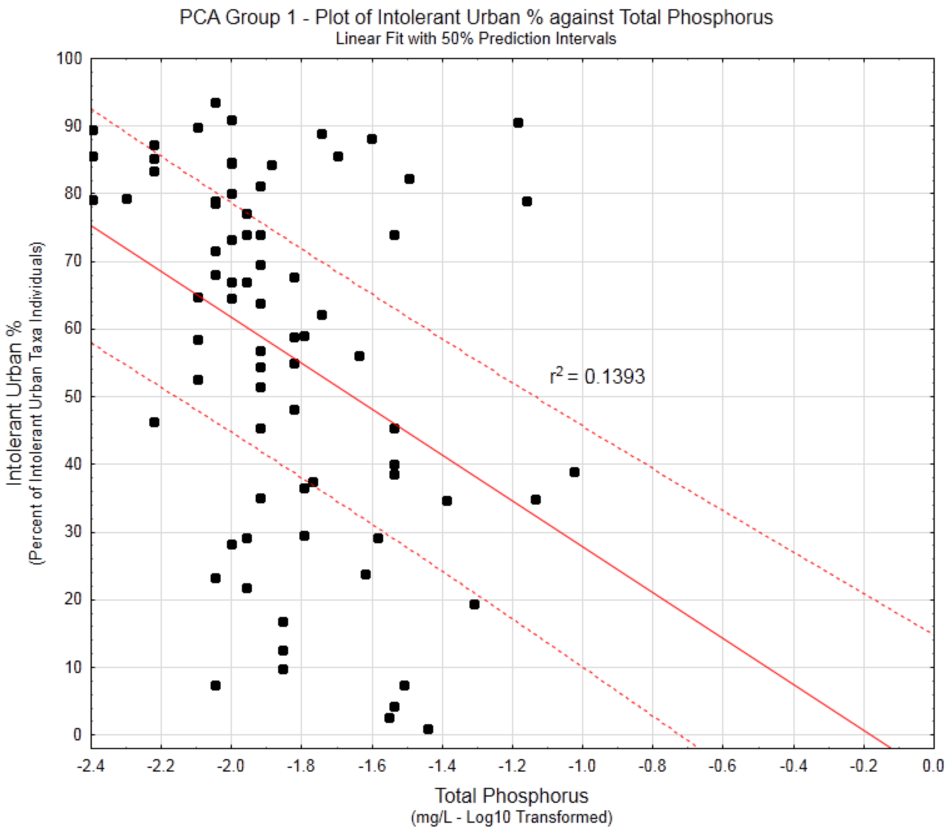
LINEAR REGRESSION AND INTERPOLATION

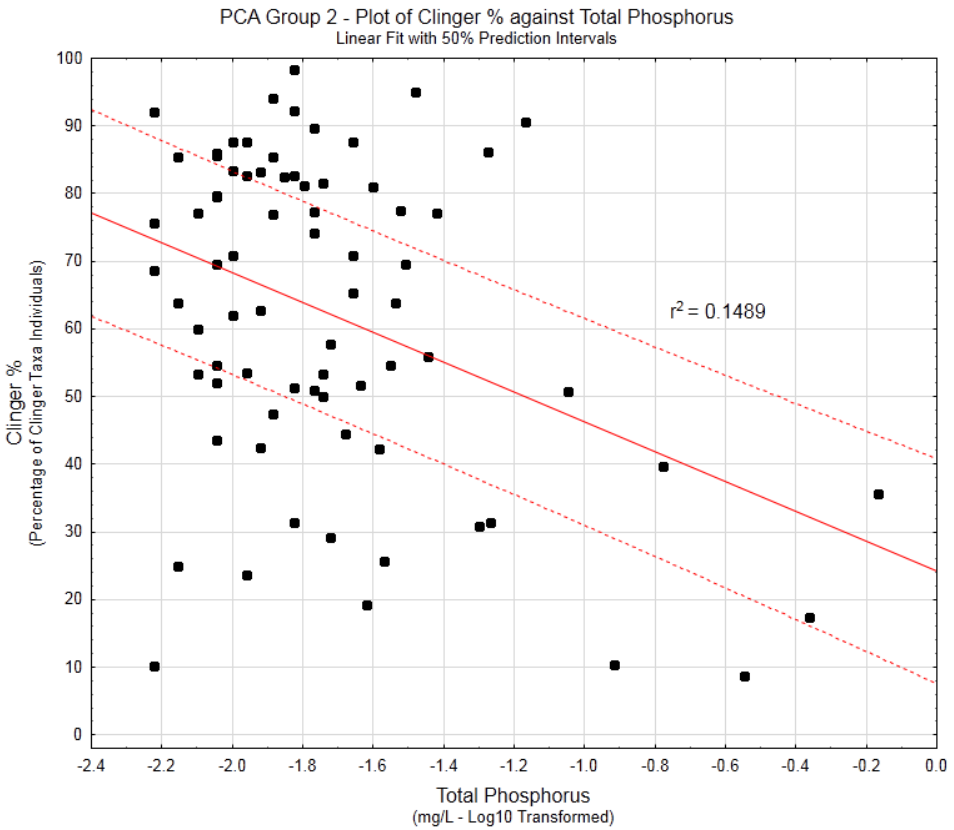
- **Removed most urban group**
- **Improved models**
- **Ecological goals defined by Index (EPT = 8)**
- **Solve for TP concentration at goal (mean and lower quartile)**



LINEAR REGRESSION AND INTERPOLATION

- **Same for other two response metrics used**



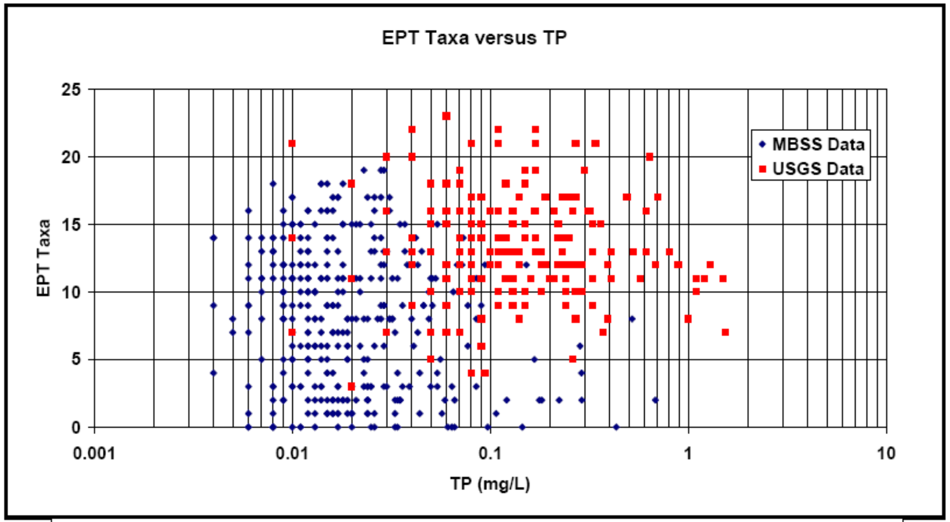


LINEAR REGRESSION AND INTERPOLATION

		Interpolated TP (ug/L)	
Metric	Groups	lower quartile	average
EPT Taxa	Group 2	10	60
	Groups 1 and 2	10	85
Percent Intolerant Urban	Group 1	16	78
	Group 2	8	82
Percent Clingers	Group 2	8	52

MODEL ACCURACY/PRECISION AND VALIDATION

- Statistical information always reported
- Validation – USGS data (Rief 1999, 2000, 2002)
- EPT Richness
- Red is USGS
- No relationships?
- Sampling issues….

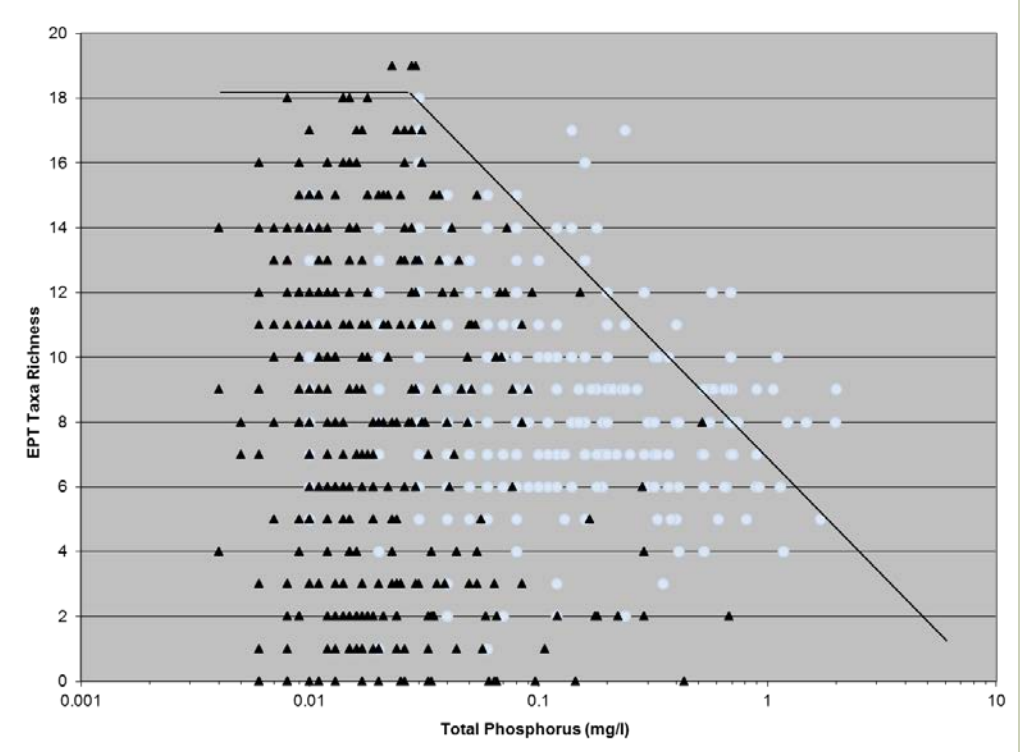


The original MBSS data used in the Paul and Zheng (2007) TP endpoint analysis was augmented with USGS data for the following 12 streams: Stony Run near Spring City; Ridley Creek at Goshenville, and at Dutton Mill near West Chester; East Branch Chester Creek at Westtown, and below Goose Creek near West Chester; Middle Branch White Clay Creek at Wickerton; East Branch Big Elk Creek at Elkview; West Branch Big Elk Creek near Oxford; Valley Creek near Atglen; West Branch Brandywine Creek, and East Branch Brandywine Creek at Wawaset; and, Brandywine Creek near Chadds Ford.

from: Hall (2008)

MODEL ACCURACY/PRECISION AND VALIDATION

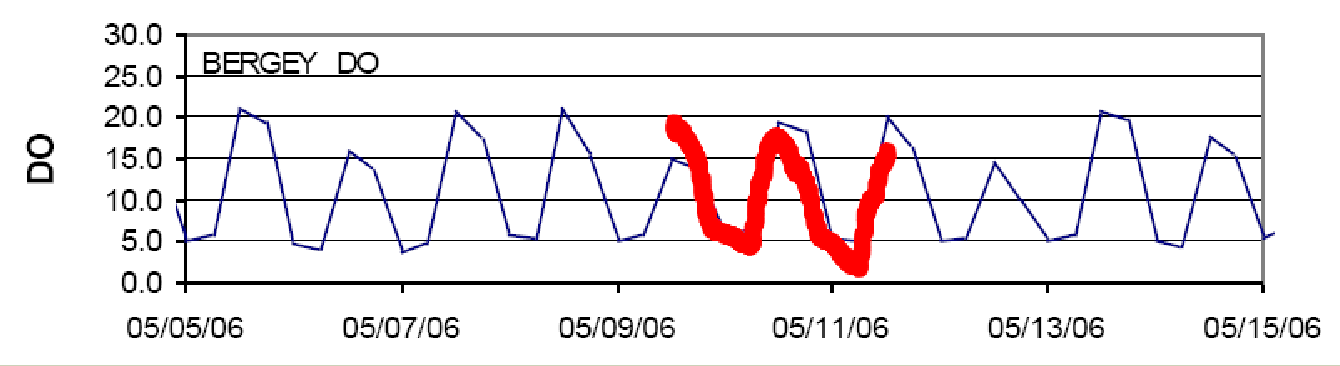
- Statistical information always reported
- Validation – USGS data (Rief 1999, 2000, 2002)
- EPT Richness – following resampling
- USGS data validates original relationship



Revisited Endpoint

MECHANISTIC MODELING INDIAN CREEK

- GWLF and EFDC models of nutrients and responses
- Model DO response
- Calibrated model to DO and then explored reductions to meet 100 mg/m^2 chl a target
- TP = 20-33 μg/L



Revisited Endpoint

REVISED TABLE

Approach		TP Endpoint (μg/L)
Reference Approach		**2-37**
	Reference Site 75th Percentile	16-17
	All Sites 25th Percentile	17
	Modeled Reference Expectation	2-37
Stressor-Response		**8-85**
	Conditional Probability – EPT taxa	38
	Conditional Probability - % Clingers	39
	Conditional Probability - % Urban Intolerant	64
	Conditional Probability - Diatoms TSI	36
	Simple linear regression interpolation – EPT taxa	10-85
	Simple linear regression interpolation – Percent intolerant urban individuals	8-82
	Simple linear regression interpolation – Percent Clinger individuals	8-52
Other Literature		**13-100**
	USEPA Recommended Regional Criteria	37
	USEPA Regional Criteria Approach – Local Data	40-51
	Algal Growth Saturation	25-50
	Nationwide Meta-Study TP-Chlorophyll	21-60
	USGS Regional Reference Study	20
	USGS National Nutrient Criteria Study	13-20
	New England Nutrient Criteria Study	40
	Virginia Nutrient Criteria Study	50
	New Jersey TDI	25-50
	Delaware Criteria	50-100
	National Reference Criteria Study	60
Mechanistic Model		**20-33**
	Indian Creek	20-33

Revisited Endpoint

TP TARGET – LINES OF EVIDENCE

- Target: remains unchanged at <u>40 μg/L TP</u>
- Stressor-responses models strengthened
  - Follow SAB reviewed S-R guidance
- Higher than distribution based approach
- Consistent with upper end modeled reference
- Consistent with mechanistic models
- Consistent with regional literature
- Multiple lines of evidence still supports original endpoint

THE END